DOCTOR OF PHILOSOPHY

A PIPELINED VECTOR PROCESSOR AND MEMORY ARCHITECTURE FOR CYCLO-STATIONARY PROCESSING

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This work describes a scaleable, high performance, pipelined, vector processor architecture. Special emphasis is placed on performing fast Fourier transforms with mixed-radix butterfly operations. The initial motivation for the architecture was the computation of cyclostationary algorithms. However, the resulting architecture is capable of general purpose vector processing as well. A major factor affecting the performance of the architecture is the memory system design. The use of pipelining techniques, coupled with vector processing, places a substantial burden on the memory system performance. The memory design is based on an interleaved memory philosophy with a buffering technique referred to as split transaction memory (STM). A crucial aspect of the memory design is the memory decoding scheme. A design methodology is described for the specification of permutation matrices that yield near optimal performance for the memory system. Another important aspect of this work is the development of a software based simulator that allows a STM to be specified. The simulator, operating at the register transfer level, emulates the processing of an address stream by STM and records the events for post-processing. The STM simulator was used to evaluate three types of vector processing address patterns: constant stride, constant geometry radix-*r* butterfly, and digit reversed. A random address pattern was also analyzed in the context of general-purpose computing. STM simulation verified the near optimal performance of the STM.

CALIFORNIA SEA BREEZE STRUCTURE AND ITS RELATION TO THE SYNOPTIC SCALE

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The sea breeze structure was examined at several locations along the California coast during the summers of 1993-1995. The sea breeze was objectively classified as three distinct types: gradual, frontal and rapid onset. The sea breeze wind and virtual temperature structure were determined at the surface and throughout the planetary boundary layer. Distinct local and regional-scale sea breeze circulations were identified for each sea breeze classification. To examine the role of the synoptic-scale wind patterns on the development of sea breeze type/structure, an objective classification scheme was developed and applied along the West Coast of California. The synoptic-scale classification scheme associated large-scale wind regimes with variability in the position of the eastern North Pacific Ocean anticyclone. Using the classification scheme, the "continental" sea and land breezes, previously only seen in long term statistical analysis, emerged as important large-scale circulation modes. The role of the synoptic-scale wind circulation patterns in determining the sea breeze types was explored. The variability in coastline geometry and inland heating sources was determined to be essential in the development and understanding of the sea breeze circulation types.

DOCTOR OF PHILOSOPHY

A MODEL AND DECISION SUPPORT MECHANISM FOR SOFTWARE REQUIREMENTS ENGINEERING

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The early portion of the software prototyping process is missing automatic support for many important activities that help the software manager and the design team members firm up requirements and control the system design and evolution to satisfy the customers' real needs. This dissertation introduces a formal model for requirements analysis and evolution and a decision support mechanism based on that model. Both the model and the decision support mechanism provide the missing support identified above. Within the framework of this model the support provided spans the whole life cycle of the software development process. The model is used to capture user reactions to the demonstrated behavior of a prototype and map these reactions into the model objects to be used in synthesizing a set of open issues to be resolved. The issues are resolved by examining and modifying requirements if necessary, and then propagating the change consequences down into the affected parts of system specification and implementations in a consistent and controlled manner.

This process is performed through a set of analysis and design activities controlled by the manager and aided by the decision support mechanism based on the formal model. This approach also provides support for maintaining design history and its rationale that can be used for implementing new needs or performing comparative studies to choose among alternatives.

A formalism is also developed that supports customers in choosing among available alternatives to requirements that satisfy their goals and meet other constraints. An improved decision support method based on this formalism supports individuals that represent different customer view points to reach a final decision that represents the combined view of the group.

A database is an important component of any decision support mechanism. This work also provides a conceptual design of an engineering database capable of representing and managing the process knowledge. This knowledge includes all information related to a software prototype design. The management of this information includes storing, retrieving, viewing, and controlling the design knowledge. The design of this engineering database is based on the object oriented paradigm. This paradigm provides the representation power to easily map our model objects and their relationships efficiently and naturally.

A new implementation model has also been developed that provides smooth and safe communication between the implementation language and the database manipulation language. The new implementation technique based on that model also allows the implementation language to directly access the database facilities. This access is done without going through intermediate layers of codes that must be implemented in another language. This is not possible without the new technique.

AN INTERPRETATION OF EXTRATROPICAL CYCLOGENESIS USING ADJOINT METHODS

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Adjoint methods are used to examine the development of idealized and real extratropical cyclones. This research represents the first use of adjoint sensitivity that includes moist physical processes to study complete cyclone life cycles. Adjoint sensitivity is a computationally efficient technique for determining, in a comprehensive sense, the sensitivity of a forecast aspect (J) to small perturbations of model variables at earlier times in a numerical forecast, including initial conditions. In these simulations, J is selected to represent central pressure or vorticity of forecast cyclones. Specification of lower tropospheric (500-800 hPa) temperature and moisture near the incipient cyclone at the

beginning of the storm track appears especially critical to cyclone prediction. Rapid cyclone intensification appears related to enhancement of dry baroclinic instability by latent heat release from nonconvective precipitation near the cyclone warm front. Cyclones can also be intensified by reduced surface stress and higher sea-surface temperature in the warm sector of the storm. The cyclone life cycle may be viewed in terms of an initially small-scale instability that propagates upward from a baroclinic zone in the lower troposphere, and leads to intensification of anomalies in both the upper and lower troposphere at the end of the storm track.

AUTONOMOUS CONTROL OF UNDERWATER VEHICLES AND LOCAL AREA MANEUVERING

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The major thrust of this work is the development and demonstration of new capabilities for the use of small autonomous vehicles in mine countermeasure applications. Key to the new capabilities lies in an open architecture tri-level software structure for hybrid control, of which this work is the first validated implementation. The two upper levels run asynchronously in computing logical operations based on numerical decision making, while the lowest, the Execution Level, runs synchronously to maintain stability of vehicle motion. The top (Strategic) Level of control uses Prolog as a rule based language for the specification of the discrete event system (DES) aspects of the mission. Multiple servo controllers are coordinated by the middle (Tactical) Level software in performing the mission, while the Execution Level controllers guarantee robust motion stability through multiple sliding modes.

This hardware/software arrangement provides the ability to operate a hybrid (mixed discrete state/continuous state) controller for semi-autonomous and autonomous vehicles in which the missions imply multiple task robot behavior. This work has defined and developed a set of vehicle "primitives", that are a set of stable modular control functions unique to a given vehicle's capabilities. It is demonstrated how these can easily be combined using rules to specify as simple, or as complex, a mission as desired. Completion of a mission is guaranteed through a "complete plan" including time traps and error recovery procedures. Experimental results are given illustrating the performance attained.

A particular case of the technique developed has resulted in a method to navigate an AUV in a local area (around a mine-like object) using a profiling sonar sensor for position information derived from underwater feature detection. Since sonar image feature extraction is necessarily time consuming, a dynamic model of the vehicle response is used for control between position updates. A structured formulation of this control/navigation method is presented followed by results from in water implementation using the NPS Phoenix vehicle and the tri-level software structure described above.

INVESTIGATION OF THE EFFECT OF TWO-DIMENSIONAL CAVITIES ON BOUNDARY LAYERS IN AN ADVERSE PRESSURE GRADIENT

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The present investigation evaluated one aspect of the feasibility of the use of multiple cavities as an airfoil high-lift device. The effects of cavities on the boundary layer characteristics in several pressure gradients were determined

experimentally and computationally. Experimentally, it was found that up to four cavities could be deployed with only a small change to the boundary layer profiles downstream of the cavities and without significantly modifying the resultant streamwise pressure distribution. From the computational results for both of the wind tunnel test section lengths used in the experimental investigation, it was found that a grid which provided a converged solution in less than a few hundred iterations was needed before a reasonable comparison with experimental data could be obtained. It was also found for these converged solutions that the appropriate grid clustering and density as well as the cell size required for a satisfactory solution was not always apparent before comparing computational results with experimental data. Overall, the investigation results show that a multiple cavity high-lift concept may be feasible.

AN ARCHITECTURAL MODEL FOR SOFTWARE COMPONENT SEARCH

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An important problem in the software development process is to make better use of software libraries by improving the search and retrieval process, that is, by making it easier to find the few components you may want among the many you do not want. The problem with the current production approaches is that they do not consider the behavior of components as a part of the retrieval process. As a result, it is impossible to obtain high recall and precision. In contrast, research approaches using syntactic and specification can be used to improve upon recall and precision. However, these approaches require a lot more computational effort. Without a library structure to support a retrieval process, they would be impractical. This dissertation concentrates on two themes. First, how to provide efficient and effective retrieval capabilities and an interactive friendly interface to support users to search for software components. Second, how to construct a library that can assist the librarian with cataloging software components and help to facilitate the search process. The first prototype has been implemented to verify the proposed ideas. Several studies have been performed to measure the system performance. The result confirms and strongly supports the proposed ideas.

OBSERVATIONS AND MODELING OF THE INTERNAL TIDE IN A SUBMARINE CANYON

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Shipboard ADCP and CTD measurements were conducted in Monterey Submarine Canyon in April and October 1994 to determine the propagation characteristics and energy levels of the semidiurnal internal tide. The measurements reveal a bottom-intensified internal tide propagating energy upcanyon. The region of strongest motion is in a beam 150-200 m thick, centered approximately 150 m above the Canyon floor. Along-canyon baroclinic M2 currents are typically 15-20 cms^{-1}, an order of magnitude larger than the estimated barotropic tidal currents. In April 1994, the internal tidal beam is well described by a progressive wave, while in October 1994, the signal is standing along and perpendicular to the beam. The Princeton Ocean Model was used to study the generation and propagation of semidiurnal internal tides in submarine canyons and to investigate their sensitivity to canyon shape. Minor changes in floor slope are found to have a significant impact on the strength of internal tides in a canyon. The numerical experiments reproduce several features of the internal tide that are in qualitative agreement with the observations, including upcanyon energy propagation along the canyon floor, internal tide generation along the canyon rim, and tidal pumping of dense water up onto the shelf near the canyon head.

DOCTOR OF PHILOSOPHY

RANGE-DEPENDENT PASSIVE SOURCE LOCALIZATION USING DATA FROM THE BARENTS SEA TOMOGRAPHY EXPERIMENT

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Matched Field Processing (MFP) and Matched-Mode Processing (MMP) are two popular techniques for passively localizing an underwater acoustic emitter in range and depth. One major drawback of these techniques has been their sensitivity to uncertainty concerning the acoustic environment. Several methods for addressing this phenomenon have been proposed in the literature, with varying degrees of success. Achieving high-quality location estimates remains a problem except in simple range-independent experiments or numerical simulations. In this study, we demonstrate an approach for robust, accurate emitter localization in a highly range dependent real environment using MMP. The main factors contributing to successful localization are: 1) use of the high-resolution Multiple Signal Classification (MUSIC) algorithm, which performs well even when only a few robust modes can be obtained by mode filtering, and 2) use of an acoustic propagation model incorporating mode coupling, which is able to generate accurate replica fields in a strongly range-dependent environment. A secondary objective of the study was to demonstrate the application of higher-order statistical estimation techniques to reduce noise effects. Our results indicate that these techniques show unacceptable sensitivity to noise- and model-induced estimation errors and require further refinement before they will be useful in the underwater acoustic localization problem.

A HIERARCHICAL APPROACH TO MULTICAST IN A DATAGRAM INTERNETWORK

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Multicasting in datagram internetworks enables multi-party interactions among users distributed over wide areas by eliminating duplicate packets in one-to-many and many-to-many communication. It requires formation of a tree to distribute multicast data to the communicating group of members.

Present multicast techniques need improvement in scope control, resource discovery mechanisms, and tree construction to efficiently support a large number of global groups with dense as well as sparse membership. We deploy a hierarchy of clustered routers with the following features to make these improvements. Each group is assigned a *scope level* enabling access to resources at that level when members join and permits well-defined boundaries for scope control. The list of border routers and presence of groups at any level is maintained and supplied to members by a level-specific resource discovery mechanism called a *registrar.* To make tree construction scaleable, the border routers determine the shortest inter-cluster paths to source clusters using the available unicast routing information, facilitating aggregation of router state for all senders in a cluster. Unlike the existing approaches, administrative configuration of the hierarchy eliminates the need for locating distribution centers dynamically.

We characterize the path length performance of the proposed hierarchy by providing an upper bound for the penalty as compared to source-specific trees. Simulation results for randomly generated topologies verify the worst case penalty and show the actual penalty to be significantly less. These results show that the proposed hierarchy can be deployed over the existing unicast routing infrastructure to achieve scaleable multicasting with the required scope control while keeping the path length penalty bounded. The architecture described permits further improvements in the path length penalty if the identified enhancements to the underlying unicast routing mechanisms are made.

DOCTOR OF PHILOSOPHY

NEW MOTION PLANNING AND REAL-TIME LOCALIZATION METHODS USING PROXIMITY FOR AUTONOMOUS MOBILE ROBOTS

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One of the most difficult theoretical problems in robotics—motion planning for rigid body robots must be solved before a robot can perform real-world tasks such as mine searching and processing. This dissertation proposes a new motion planning algorithm for an autonomous robot, as well as the method and results of implementing this algorithm on a real vehicle.

This dissertation addresses the problem of safely navigating an autonomous vehicle through free space of a two dimensional, world model with polygonal obstacles from a start configuration (position/orientation) to a goal configuration using smooth motion under the structure of a layered motion planning approach. The approach proposes several new concepts, including *v-edges* and *directed v-edges,* and divides the motion planning problem of a rigid body vehicle into two subproblems: (i) finding a global path using Voronoi diagrams and for a given start and goal configurations planning an optimal global path; the planned path is a sequence of directed v-edges, (ii) planning a local motion from the start configuration, using the aforementioned global path. The problem of how to design a safe and smooth path, is effectively solved by the steering function method and proximity. Another problem addressed here is how to make a smooth transition when the vehicle gets closer to an intersection of two distinct boundaries.

This dissertation also presents a robust algorithm for the vehicle to continually eliminate its positional uncertainty while executing missions. This functionality is called *self-localization* which is an essential component of model-based navigation for indoor applications. This algorithm is based on the two-dimensional transformation group. Through this method, the robot can minimize its positional uncertainty, make safe and reliable motions, and perform useful tasks in a partially known world.

All of the proposed algorithms were implemented on an autonomous mobile robot *Yamabico-l l* to confirm our analytical results.